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Streamflow After Patch Logging in Small Drainages Within the Bull Run Municipal Watershed, Oregon

R. Dennis Harr

Cover photograph:
Fireweed (Epilobium angustifolum L.) growing in a clearcut in watershed FC-1 six years after logging residue was broadcast burned.

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STREAMFLOW AFTER PATCH LOGGING IN SMALL DRAINAGES WITHIN THE BULL RUN MUNICIPAL WATERSHED, OREGON

Reference Abstract

Harr, R. Dennis.
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Annual water yields and size of peak flows were not changed, but low flows decreased significantly after patch logging in two small watersheds.

KEYWORDS: Streamflow -)forestry methods, logging (-hydrology, patch logging, Oregon (Bull Run Watershed)

Research Summary

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Three experimental watersheds in the City of Portland's Bull Run Municipal Watershed were used to determine effects of patch logging on timing and quantity of streamflow. Annual water yields and size of instantaneous peak flows were not significantly changed, but low flow decreased significantly after logging of two small watersheds in small, clearcut patches totaling 25 percent of each watershed's area.

Contents

Introduction

Changes in annual water yield, minimum streamflow, and instantaneous peak flow (the maximum rate of streamflow caused by a rain or snowmelt event) are all important in municipal watershed management. If timber cutting can increase water yield, then a municipal watershed might be made to yield more water, particularly during the summer period of low flow. Increased size of peak flows as a result of timber harvest might be associated with not only overland flow and attendant surface erosion but also erosion of stream channels. Both factors could adversely affect water quality.

In 1955, the USDA Forest Service and the City of Portland, Oregon, began a cooperative study to determine effects of timber harvest on water yield and timing of runoff and the quality of streamflow in three small watersheds within the Bull Run Municipal Watershed. This report deals only with changes in quantity and timing of streamflow.

Studies in other parts of the country have illustrated the size of increases in annual water yield after timber harvest. Results of these studies, many of which were summarized by Hibbert (1967), indicate that the size of the increase in water yield is roughly proportional to the percentage of a watershed that is clearcut. Subsequent studies in the Pacific Northwest have shown that 1st-year increases in annual water yield may be more than 50 cm in small, upland watersheds (Rothacher 1970, Harr 1976, Harris 1977, Harr et al. 1979). In absolute terms, the greatest part of each annual increase has occurred during the fall-winter rainy season, but the largest relative increases have occurred during the summer (Rothacher 1970, 1971; Harr et al. 1979).

Numerous studies throughout the United States have also described changes in the size and timing of instantaneous peak flows after logging (for example, Reinhart et al. 1963, Hewlett and Helvey 1970, Hornbeck 1973). In general, where soil disturbance had been minimal, changes in storm runoff were restricted to those seasons when reduced evapotranspiration after timber cutting caused differences in water content of the soil between logged and unlogged watersheds. Because of wetter soils at the end of the growing season, logged watersheds were hydrologically more responsive to rainfall and exhibited higher peak flows. This has caused size of peak flows in the fall to be greater the first few years after timber harvest in the Pacific Northwest (Rothacher 1973, Harr et al. 1975). As revegetation has proceeded, evapotranspiration and fall peak flows have trended toward their prelogging levels.

Some studies in the Pacific Northwest reported changes in size and timing of peak flows that appear to have been related to factors other than wetter soils caused by reduced evapotranspiration. Where soils in more than 12 percent of the total watershed area were compacted by timber harvest activities, the size of large, winter peak flows in small upland watersheds was increased 20 to 48 percent according to comparison of prelogging and postlogging relations between logged and unlogged watersheds (Harr et al. 1975, Harr et al 1979). In another study, delay and decreased size of peak flows after clearcut logging were attributed to changes in short-term snow accumulation and melt (Harr and McCorison 1979). In a watershed study in western British Columbia, soil disturbance during yarding apparently disrupted water-transmitting pores and forced water through slower routes in the soil, which caused delayed smaller peak flows after logging (Cheng et al. 1975). Taken collectively, these studies indicate size of peak flows may increase, decrease, or remain unchanged after timber harvest, depending on what part or parts of the hydrologic system are altered by timber harvest activities.

The objective of this study was to determine the effects of timber harvest on annual water yield, low flows, and instantaneous peak flows in small headwater basins in the Bull Run Municipal Watershed.

The Study

Watershed Characteristics

The study area consists of three small watersheds in the Fox Creek drainage, a tributary to the South Fork Bull Run River, 40 km east of Portland, Oregon (fig. 1). The watersheds, which are designated Fox Creek 1 (FC-1), Fox Creek 2 (FC-2), and Fox Creek 3 (FC-3), are 59 ha, 253 ha, and 71 ha in size. Sideslope gradients of the watersheds average only 5-9 percent but range up to 60 percent near the watersheds' outlets. The relatively gentle topography is representative of perhaps 25-30 percent of the Bull Run Municipal Watershed. Elevation ranges from 840 m to 1 070 m. Most soils have formed from igneous glacial till overlying basalt and andesite, are loamy in texture with depths of 1-3 m, and exhibit moderately rapid percolation capacities. Overland flow has not been observed in the undisturbed forests of the Fox Creek Watersheds. Overstory vegetation is primarily old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) mixed with younger Pacific silver fir (*Abies amabilis* (Dougl.) Forbes).

Since precipitation measurements began in 1957, annual precipitation has averaged 273 cm at the elevation of the watershed outlets, about 83 percent of which has fallen during the October-April period (fig. 2). Annual snowpack, which varies greatly from year to year,

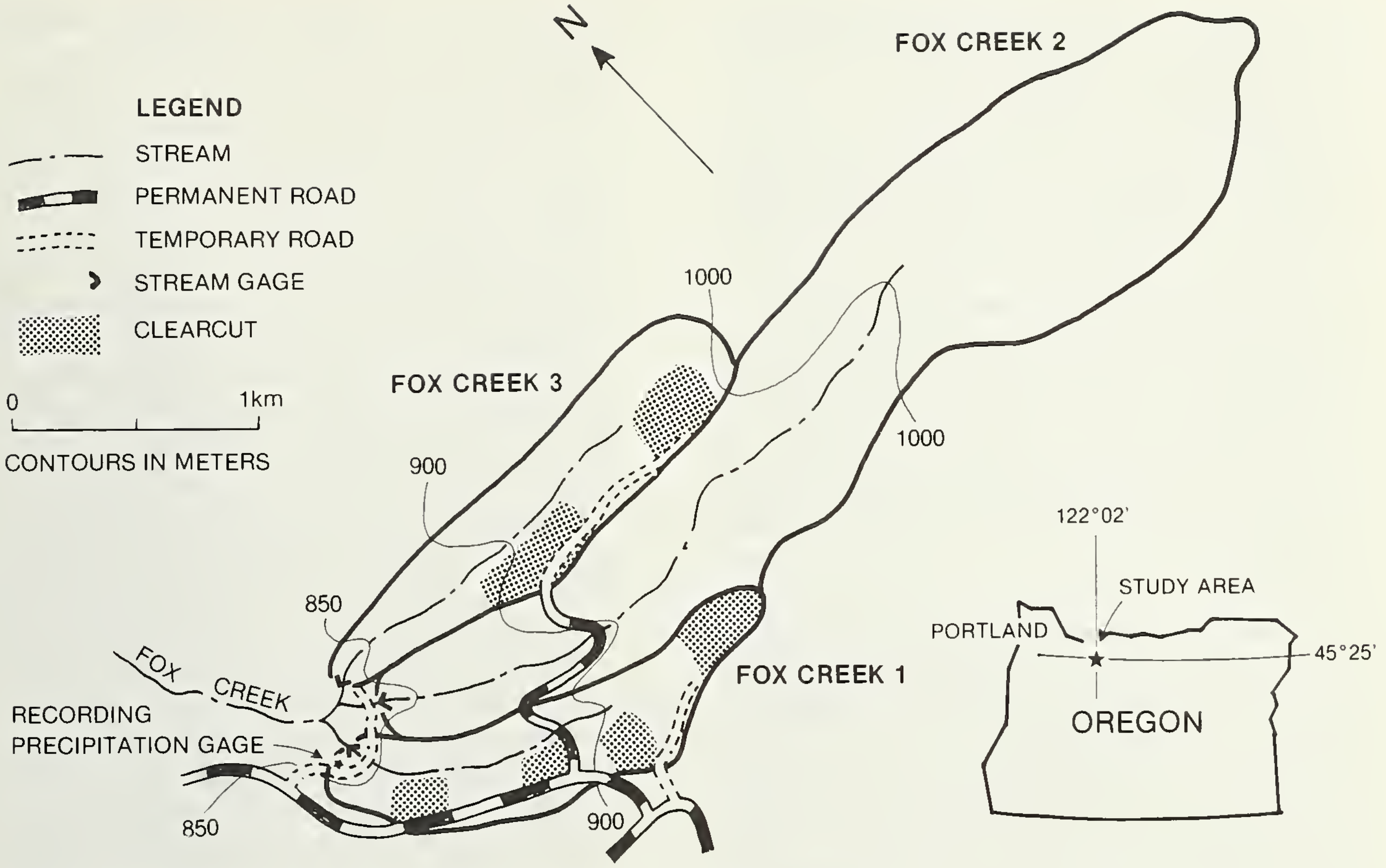

Figure 1.--The Fox Creek Experimental Watersheds.

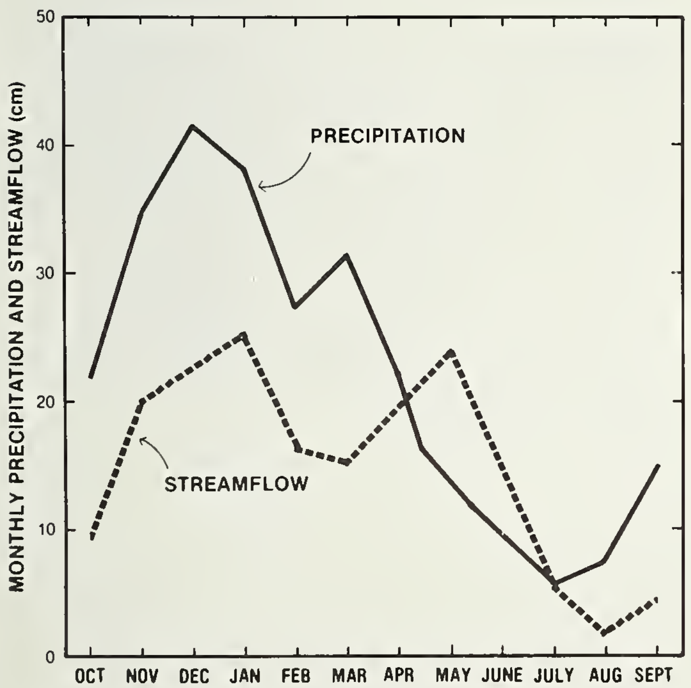

Figure 2.--Mean monthly precipitation at Fox Creek gage and streamflow at watershed FC-2, 1959-1977.

may begin accumulating in November and reach a maximum depth of more than 1.5 m by early April. During the summer, considerably more precipitation falls here than in most other areas of western Oregon. Also, fog or cloud interception by forest trees--and resultant drip--could be an additional, unmeasured source of precipitation. Fog drip has been described by field crews who have experienced "rainfall" (fog drip) under the forest canopy in all seasons, but found no water in the rain gage located in an open area nearby.

Streamflow, which has been measured continuously by trapezoidal flumes since the beginning of the 1957 water year (a water year runs from October 1 to September 30), has an annual pattern of distribution that reflects the general climatic pattern of the area (fig. 2). Typically, the major annual peak, which usually occurs in November, December, or January, results from rainfall or rapid snowmelt during rainfall. A second peak, which may be the maximum annual streamflow in any one year, often occurs during snowmelt in April or May. Minimum streamflow usually occurs between mid-August and mid-September.

Total annual water yield has varied considerably among the three watersheds. During 11 prelogging years, it averaged 235 cm at FC-3, 271 cm at FC-1 and, during 20 years of record, has averaged 175 cm at FC-2, the unlogged control watershed. These yields are 83, 94, 64 percent of average annual precipitation for the same periods. This variation in runoff percentage is greater than would be expected for three similar watersheds located adjacent to one another and is much greater than corresponding variation observed in similar studies elsewhere in the western Cascades of Oregon (Rothacher 1970, Harr et al. 1979). Part of the variation results from differences in annual precipitation caused by differences in elevation of the watersheds. Adjustment of annual precipitation by the isohyetal method yields average annual precipitation values of 279 cm, 294 cm, and 284 cm for FC-1, FC-2, and FC-3, respectively. Another part of the variation may result from inaccurate determination of watershed boundaries, particularly along the upper ends of FC-1 and FC-2, where the ground surface is nearly level. Moreover, if fog drip is a significant source of precipitaton and is unequally distributed among the three watersheds, such unequal distribution also may account for some of the variation in average annual yields.

Harvest Activities

In August 1965, a 1-km all-weather road was completed across gentle topography in FC-1 and FC-2 to the south boundary of FC-3 (fig. 1). In addition, short temporary spur roads were built into the areas to be logged in FC-1 and in FC-3. In FC-1, timber was clearcut in four units of 3-4 ha in late spring of 1969, and high-lead yarding was completed in July. Logging residue in the four logged units was burned in the fall of 1970. Logging in FC-3 occurred over a 3-year period; cutting in two units of 8-10 ha began in the summer of 1970, and yarding was completed in August 1972. Both tractors and a high-lead cable system were used to yard logs. No residue was burned in FC-3. Logged area in each watershed constitutes 25 percent of the total watershed.

Data Analysis

In this type of study, relationships developed between logged and unlogged watersheds during a prelogging calibration period are far more important than absolute values of various streamflow characteristics. These relationships are the bases for evaluating changes in annual water yield, low flows, and instantaneous peak flows after logging. Annual water yield data were summed simply by water year, but summer low-flow data were summarized two ways. First, monthly water yields were summed by watershed for each consecutive month that monthly water yield at the unlogged FC-2 watershed was less than 5 cm, an arbitrary value. July, August, and September were the most common consecutive months of low flow, but the number of months did range from only one (July 1968 and August 1971) to five (June-October 1965 and July-November 1976). In a second analysis, the number of days of streamflow below a predetermined low-flow level was compared between the unlogged watershed and each of the patch logged watersheds. A low-flow day is defined as having a mean daily streamflow of less than 0.11 liters/s·ha (1 $ft^3/s \cdot mi^2$), again an arbitrary value. Annual water yield, low flow, and number of low-flow days at each logged watershed were then regressed on corresponding values of each variable at the control watershed.

Instantaneous peak flows greater than 5.6 liters/s·ha at FC-2, the control watershed, and corresponding peak flows at logged watersheds were tabulated by water year. (A frequency analysis shows that a peak flow of 5.6 liters/s·ha at FC-2 would occur, on the average, at least once a year.) Peak flow at each patch logged watershed was regressed on peak flow at the uncut watershed for both prelogging and postlogging periods. Because the major peak flows of December 1964 and January 1965 were estimated at FC-1, these two events were excluded from analysis of peak-flow data. There were 14 events in each of the prelogging and postlogging periods in the FC-1 analysis, and 18 prelogging and 12 postlogging events in the FC-3 analysis.

Linear regression was used to obtain prelogging and postlogging prediction equations for estimating annual water yields, low flows, and peak flows at FC-1 and FC-3 from values of these variables at FC-2. A difference between prelogging and postlogging data was hypothesized and tested by comparing two regression lines (Neter and Wasserman 1974, p. 160-167). For each streamflow variable, the hypothesis was that there was no difference between the two regressions; i.e., $\alpha_1 = \alpha_2$ and $\beta_1 = \beta_2$, where α is the intercept of the regression, β is the slope, and subscripts 1 and 2 denote prelogging and postlogging, respectively. If the computed F value used to compare mean squares was greater than the tabulated value, the hypothesis was rejected in favor of the alternate hypothesis that the prelogging and postlogging regressions are different.

Results and Discussion

Water Yield

Prelogging and postlogging regression equations for annual water yield are given in table 1 and are plotted in figures 3 and 4. I failed to reject the hypothesis that prelogging and postlogging regressions are not different. There is a possibility that postlogging yields may have been decreased slightly (about 6 percent) at both watersheds, because postlogging regressions are below the prelogging regression lines. Such decreases, of course, are not statistically significant at the 0.05-level of probability. If, however, a probability level of 0.10 had been chosen to test hypotheses, then prelogging and postlogging regressions at FC-1 would be significantly different.

Based on results of other water-yield studies in western Oregon, modest increases in yield had been expected in both patch logged watersheds. Because removing forest vegetation reduces annual evapotranspiration (interception losses and transpiration), more of the annual precipitation becomes available for streamflow. In a 101-ha watershed in the H. J. Andrews Experimental Forest east of Eugene, Oregon, where three clearcut patches and clearing for roads totaled 30 percent of watershed area, increases in annual yield averaged about 17 cm 3 years after logging, compared to 46 cm on a 96-ha watershed that was completely clearcut (Rothacher 1970). In southwestern Oregon, water-yield increases averaged 9 cm the first 5 years after a 68-ha watershed was logged in 20 small clearcuts totaling 38 percent of watershed

Table 1--Prelogging and postlogging water yield relationships between logged watersheds ($\hat{Y}$) and the control watershed (X)

Watershed and period	Equation	n	r^2	F
FC-1 prelogging	$\hat{Y} = 0.53 + 1.55X$	8	0.84	[1]3.43
FC-1 postlogging	$\hat{Y} = 14.81 + 1.39X$	9	.99	
FC-3 prelogging	$\hat{Y} = -21.57 + 1.49X$	9	.91	[1]1.79
FC-3 postlogging	$\hat{Y} = 12.93 + 1.26X$	8	.99	

[1]Prelogging and postlogging regressions are not significantly different at the 0.05-level of probability.

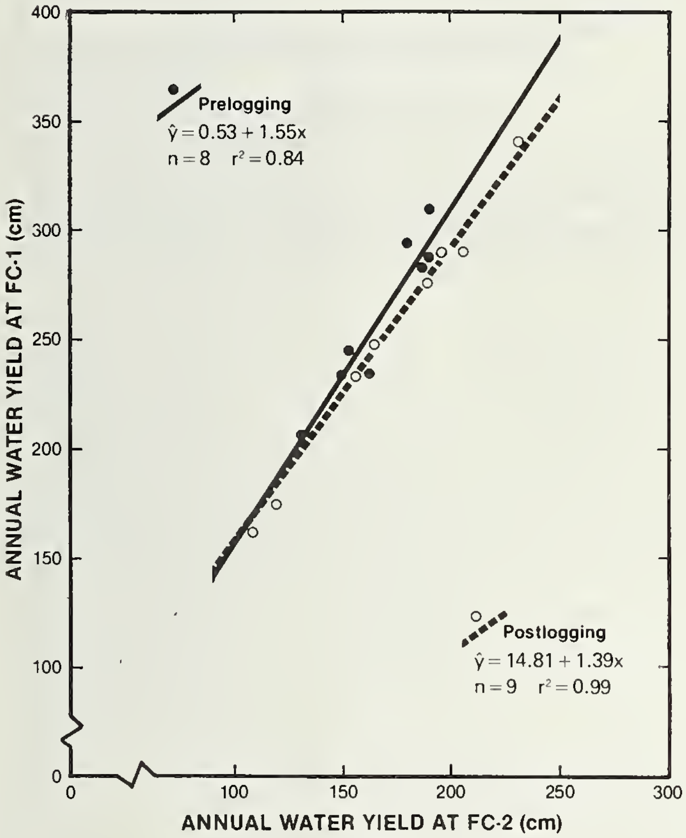

Figure 3.--Annual water-yield relationship between FC-1 and control watershed FC-2.

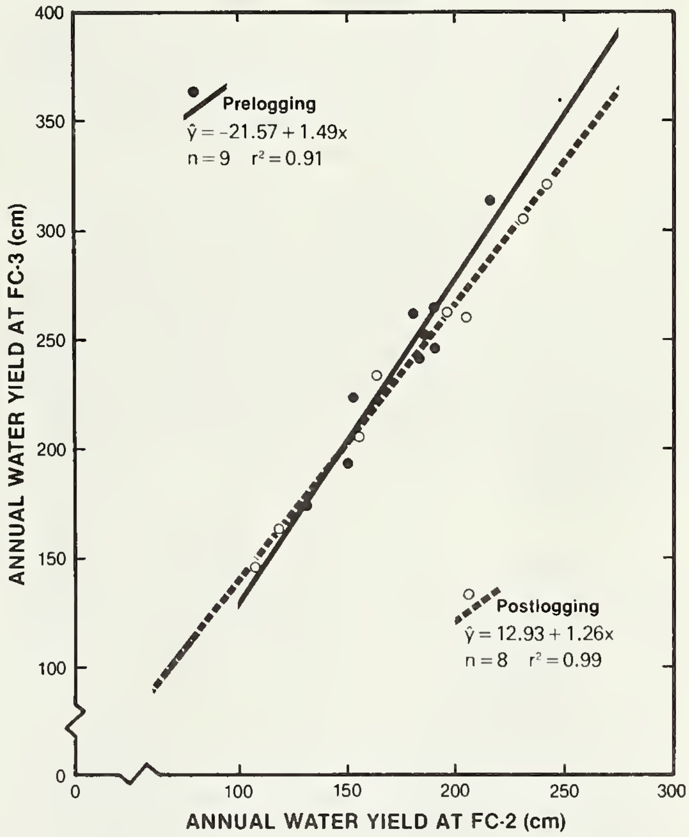

Figure 4.--Annual water-yield relationship between FC-3 and control watershed FC-2.

area (Harr et al. 1979), compared to a 30-cm average water-yield increase in an adjacent 50-ha watershed that was completely clearcut. Considering these measured increases and estimated annual losses to interception and transpiration at Fox Creek of at least 80 cm (U.S. Army Corps of Engineers 1956, p. 131-136, Luchin 1973), yield increases of about 10-15 cm had been expected.

Lack of expected increases in annual yield may have several possible causes. The first possibility was that FC-2 streamflow was changed by logging. If, because of obscure groundwater divides in some locations, the clearcuts in FC-3 and the upper clearcut in FC-1 (fig. 1) actually were located partially within the FC-2 groundwater basin, some of the effect of timber cutting on streamflow could have been included in streamflow measurement at the FC-2 stream gage. This would cause FC-2 annual yield to be greater than would otherwise be the case and could account for post-logging data points being below the prelogging regression lines in figures 3 and 4.

A change in FC-2 streamflow should be visible in a double-mass plot of streamflow and precipitation. As can be seen in figure 5, there is a distinct change in slope in the double-mass curve shortly after logging in FC-3. This slope change, however, is not conclusive evidence that FC-2 streamflow was changed after logging, for the slope change could also result from a change in precipitation measurement. Indeed, a double-mass plot of FC-2 precipitation versus precipitation at Bull Run Headworks, 9 km northwest of FC-2, shows an identical slope change (fig. 6). This supports a

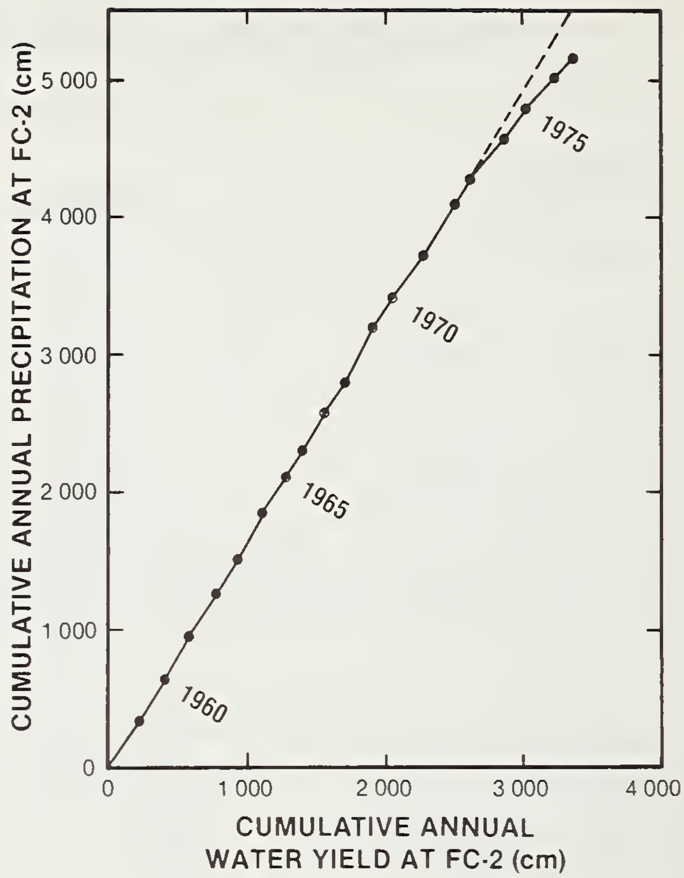

Figure 5.--Double-mass plot of cumulative annual precipitation and cumulative annual water yield at FC-2.

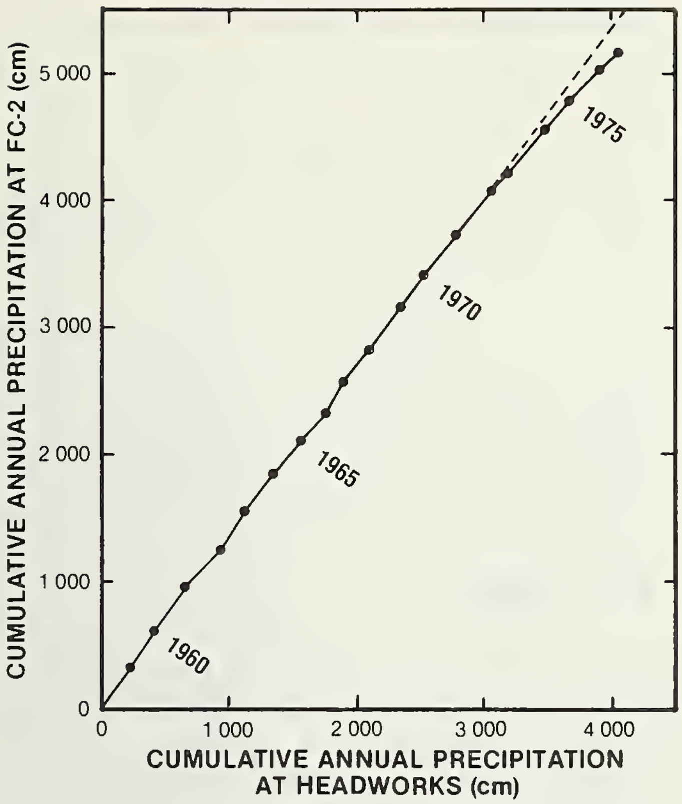

Figure 6.--Double-mass plot of cumulative annual precipitation at FC-2 and cumulative annual precipitation at Bull Run Headworks.

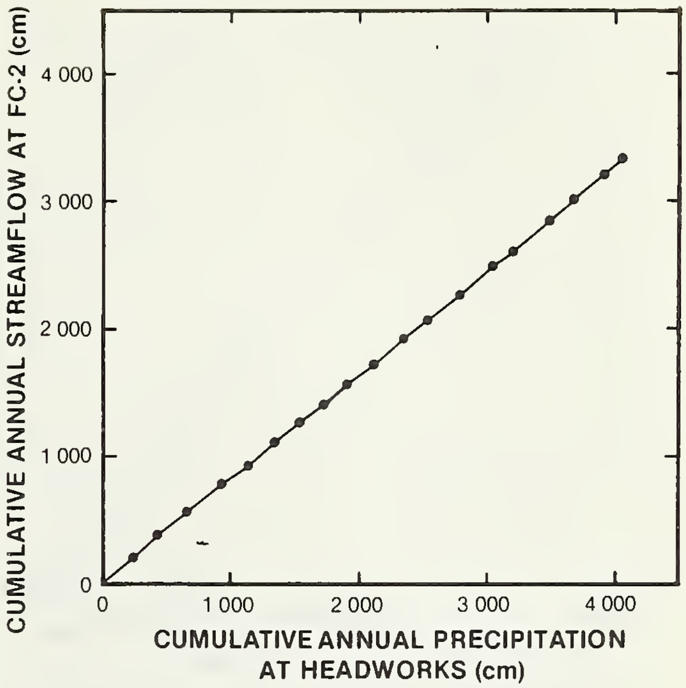

Figure 7.--Double-mass plot of cumulative annual streamflow at FC-2 and cumulative annual precipitation at Bull Run Headworks.

change in precipitation measurement at FC-2 as the explanation. Before February 1972, precipitation measurements at the recording rain-gage were not adjusted according to measurements with a standard storage gage, as is done currently. They could be about 2-4 percent higher than post-1972 measurements. Precipitation measurement rather than a change in FC-2 streamflow is the cause of the slope change in figure 5. That a double-mass plot of annual streamflow at FC-2 versus annual precipitation at Bull Run Headworks (fig. 7) shows no change in slope substantiates that annual streamflow at FC-2 has been unchanged by logging in FC-1 or FC-3.

The lack of expected increases in annual water yield also may involve fog or cloud interception by the forest canopy. If the forest stands that were cut had intercepted water droplets in clouds, and subsequent drip from these stands was an important (though unmeasured) part of net precipitation, then removing these stands might have reduced total annual gross precipitation sufficiently to offset reduced transpiration from clearcut areas. The amount of fog or cloud interception at Fox Creek and its distribution over the study watersheds are unknown, but fog drip could be as high as 25-30 cm, according to results of several studies of fog interception along the Pacific coast. In general, these studies have shown that amount of drip is directly related to the area of tree profile and to the degree of exposure of trees to windblown fog.

On the Oregon coast, annual precipitation under the forest canopy was 252 cm, 52 cm (26 percent) greater than in the open (Isaac 1946). During a 46-day summer period in coastal northern California, fog drip beneath 18-m-tall Douglas-fir trees ranged up to 42.5 cm (Azevedo and Morgan 1974). In Hawaii, Ekern (1964) measured 76 cm of annual fog drip under a 9-m-tall pine tree, a 20 percent increase. Other published fog drip measurements include 152.4 cm and 5.2 cm beneath an exposed tanoak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.)) tree and a sheltered redwood (*Sequoia sempervirens* (D.Don) Endl.) tree, respectively, during the summer (Oberlander 1956) and 5.7 cm per month beneath knobcone pine (*Pinus attenuata* Lemm.) in southern California (Vogl 1973).

Amounts of fog drip measured in most of these studies are probably much greater than fog drip at the Fox Creek site. Even so, fog drip of 25-30 cm beneath the forest canopy at Fox Creek may not be an unreasonable estimate. Fog drip seems to be the most plausible explanation, so far, for the lack of increase in water yield after logging. Measurement of actual fog drip at Fox Creek and assessment of its importance in annual precipitation are necessary before the effects of timber cutting on streamflow are completely understood for these small watersheds. Results from a fog drip study now underway will be reported as they become available.

Low Flows

Prelogging and postlogging regression equations for low flow during low-flow months are given in table 2, and relations for each period are plotted in figures 8 and 9. Prelogging and postlogging regressions are significantly different at FC-1, but not at FC-3 (table 2); streamflow at FC-1 was reduced, on the average, about 15-20 percent during the low-flow period.

Table 2--Prelogging and postlogging low-flow relationships between logged watersheds ($\hat{Y}$) and the control watershed (X)

Watershed and period	Equation	n	r^2	F
FC-1 prelogging	$\hat{Y} = 0.23 + 2.02X$	11	0.97	1/9.63
FC-1 postlogging	$\hat{Y} = -.16 + 1.72X$	9	.98	
FC-3 prelogging	$\hat{Y} = .42 + 1.22X$	12	.82	2/.35
FC-3 postlogging	$\hat{Y} = .64 + 1.08X$	7	.87	

1/Prelogging and postlogging regressions are different at the 0.05-level of probability.

2/Prelogging and postlogging regressions are not significantly different at the 0.05-level of probability.

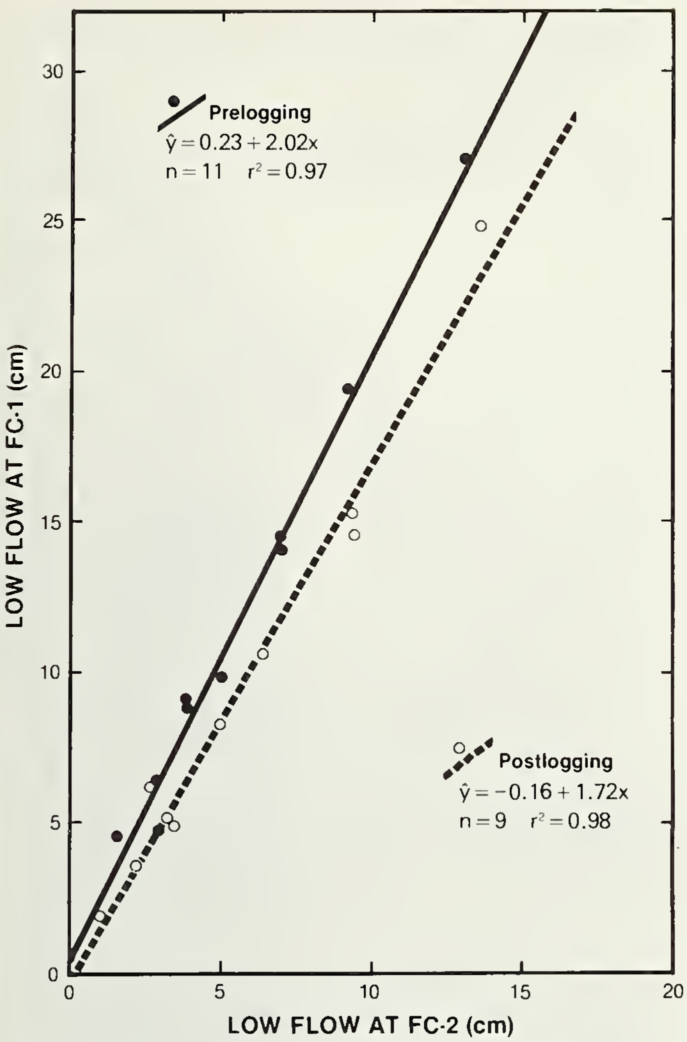

Figure 8.--Relationship of low flow between patch logged FC-1 and unlogged FC-2.

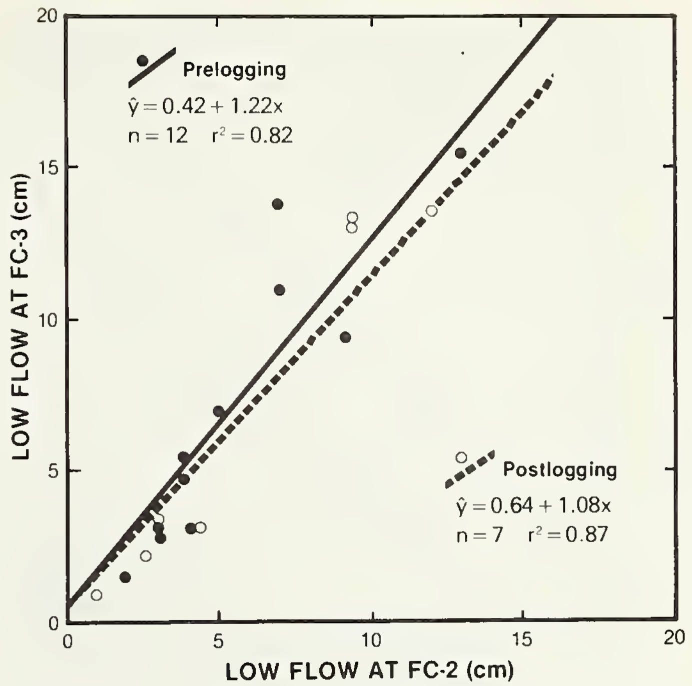

Figure 9.--Relationship of low flow between patch logged FC-3 and unlogged FC-2.

Prelogging and postlogging regression equations for number of low-flow days are given in table 3, and each period's relationships are plotted in figures 10 and 11. Prelogging and postlogging regressions are significantly different at both

Table 3--Prelogging and postlogging low-flow day relationships between logged watersheds ($\hat{Y}$) and the control watershed (X)

Watershed and period	Equation	n	r^2	F
FC-1 prelogging	$\hat{Y} = -28.33 + 0.93X$	11	0.83	1/9.31
FC-1 postlogging	$\hat{Y} = 9.50 + .99X$	9	.29	
FC-3 prelogging	$\hat{Y} = -25.78 + 1.26X$	12	.90	1/6.93
FC-3 postlogging	$\hat{Y} = 27.31 + .81X$	8	.59	

1/Prelogging and postlogging regressions are significantly different at the 0.05-level of probability.

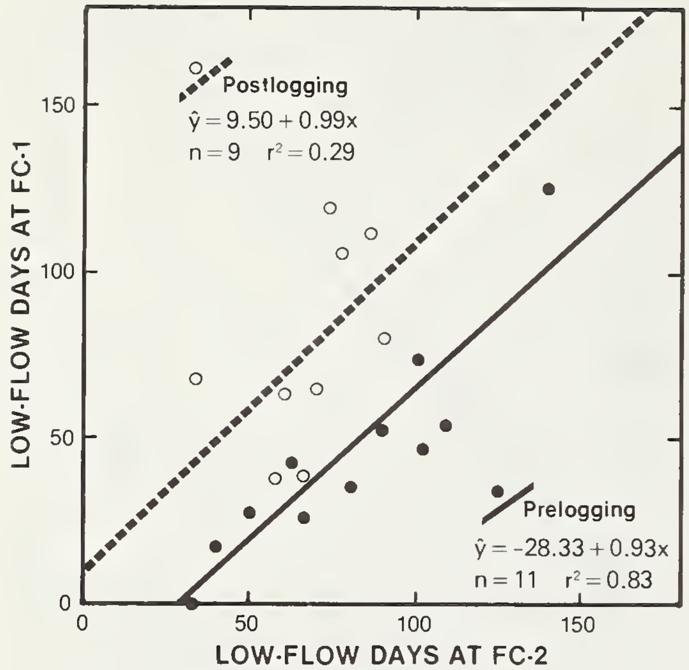

Figure 10.--Relationship of low-flow days between patch logged watershed FC-1 and unlogged FC-2.

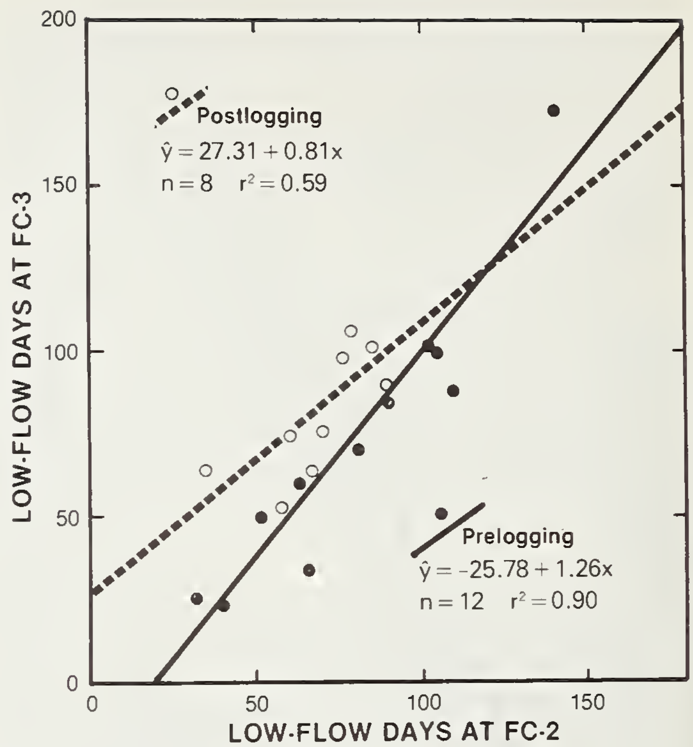

Figure 11.--Relationship of low-flow days between patch logged watershed FC-3 and unlogged FC-2.

FC-1 and FC-3; number of low-flow days increased relative to the number at FC-2--that is, streamflow during the low-flow period was reduced after clearcutting in patches.

Reduced summer flow as illustrated by both low-flow analyses at FC-1 and one analysis at FC-3 could also result from fog drip. If fog drip had added to total basin precipitation before logging, then removing timber stands that intercepted fog could have reduced effective precipitation and thus streamflow during summer low-flow periods.

Increased flows during summer low flow had been expected because timber cutting would make more water available for streamflow, particularly during the summer when forest vegetation is withdrawing water from the soil. Watershed studies elsewhere in Oregon have shown large relative increases in streamflow during the months of lowest flow. In the H. J. Andrews Experimental Forest, Rothacher (1971) found that average streamflow during the week of lowest flow tripled the year after a 96-ha watershed was clearcut and broadcast burned. Increases in summer flows were also noted at a nearby 101-ha watershed that was patch logged, but those increases were much smaller (Rothacher 1970). In the Oregon Coast Ranges, low flows were significantly increased all five postlogging years in a 70-ha watershed that had been 82-percent clearcut (Harr and Krygier 1972). At a second watershed which had been 25-percent clearcut in patches, increases in low flows were significant in only two of five postlogging years. In southwestern Oregon, streamflow during the July-September low-flow season was increased up to 400 percent the first 6 years after 100-percent

clearcutting one watershed, up to 200 percent after patch logging a second watershed, and up to 80 percent after shelterwood cutting a third watershed (Harr et al. 1979).

Peak Flows

Prelogging and postlogging regression equations for peak flows are given in table 4, and relationships for each period are plotted in figures 12 and 13. In general, peak flows at FC-1 and FC-3 were not well correlated with corresponding peak flows at FC-2 during both prelogging and postlogging periods as evidenced by three r^2 values of only 0.59 to 0.74. Prelogging and postlogging relationships are not significantly different at either watershed. This was partly because of (1) natural variation in runoff production between watersheds owing to differences in watershed size and elevation, (2) relatively small numbers of peak-flow events suitable for analysis, and (3) probably only a very slight effect of logging on size of peak flows.

Significant increases in size of peak flows had not been expected because only 25 percent at FC-1 and FC-3 were logged, soil was disturbed on a very small part of the watersheds, and the gentle topography of the watersheds tends to reduce the likelihood of overland flow reaching a water course. Rothacher (1973) found increases in size of small peak flows only in the fall and spring after a steep 96-ha watershed was completely clearcut with little soil disturbance. Increases were attributed to wetter, hydrologically more responsive soils after logging because evapotranspiration had been reduced. After soils in the forested control watershed had been recharged, both forested and clearcut watersheds responded similarly, so that large peak flows in winter were nearly unchanged. Likewise, Harris (1973) found no significant increase in size of large peak flows in winter after clearcutting in a 71-ha watershed in the Oregon Coast Ranges. On the other hand, comparison of prelogging and postlogging peak flow relationships indicated size of winter peak flows at two other locations in

Table 4--Prelogging and postlogging peak-flow relationships between logged watersheds ($\hat{Y}$) and the control watershed (X)

Watershed and period	Equation	n	r^2	F
FC-1 prelogging	$\hat{Y} = -0.88 + 1.43X$	14	0.74	1/ 1.26
FC-1 postlogging	$\hat{Y} = -1.38 + 1.58X$	14	.59	
FC-3 prelogging	$\hat{Y} = -.44 + 1.20X$	18	.91	1/ .96
FC-3 postlogging	$\hat{Y} = -2.01 + 1.60X$	12	.69	

1/ Prelogging and postlogging regressions are not significantly different at the 0.05-level of probability.

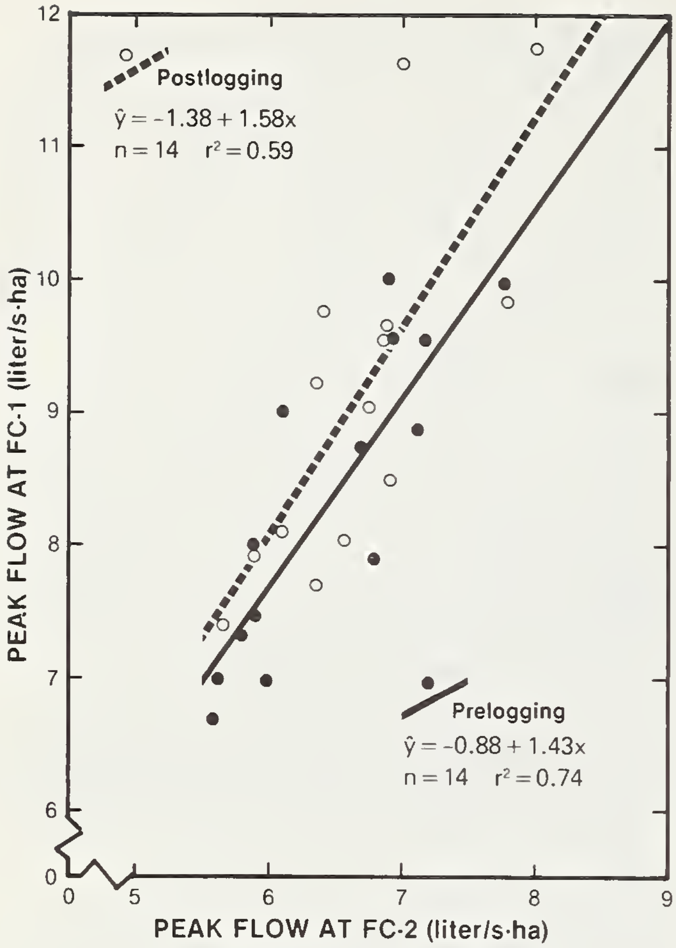

Figure 12.--Peak-flow relationships between patch logged FC-1 and unlogged FC-2.

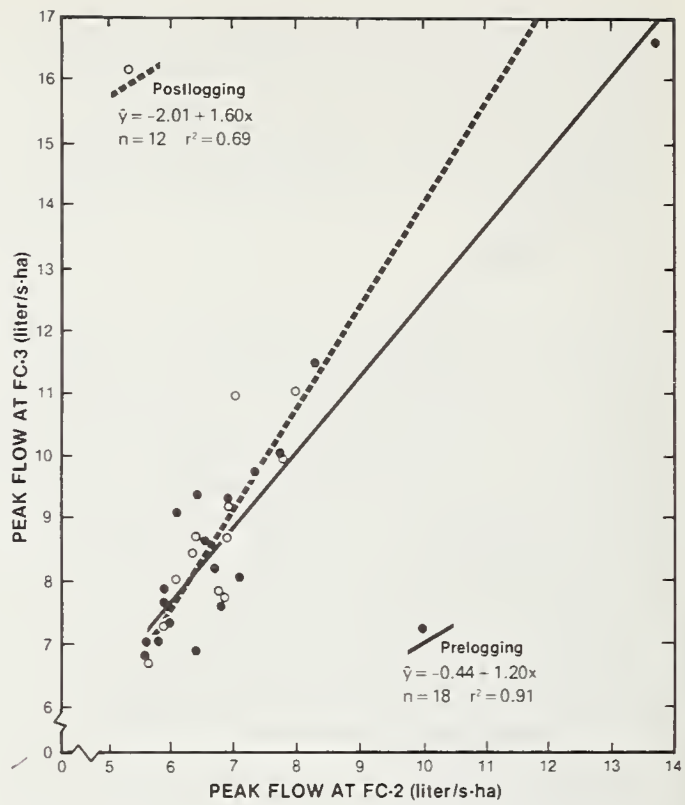

Figure 13.--Peak-flow relationships between patch logged FC-3 and unlogged FC-2.

western Oregon were significantly increased where compacted soils occupied at least 12 percent of total watershed area (Harr et al. 1975, Harr et al. 1979).

Where similar patch logging with minimal soil disturbance is done in other drainages in the 25-30 percent of the 270-km Bull Run Watershed that has slope gradients of <15 percent, size of instantaneous peak flows in winter most likely would not be changed. One exception may involve rapid snowmelt during rainfall. Comparing point estimates of snowmelt during rainfall for

forested and open areas (U.S. Army Corps of Engineers 1960) suggests that clearcutting on certain areas may increase the rate of snowmelt by increasing the rate of air movement and, thus, the amount of melt resulting from convective heat exchange and condensation of water vapor on the snow surface. Convection-condensation melt is the largest component of total melt under most rainfall conditions in this region.

Conclusions

Annual water yield and size of instantaneous peak flows were not significantly changed, but low flow decreased significantly after two experimental watersheds were logged in small clearcuts totaling 25 percent of watershed area.

Acknowledgments

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Literature Cited

Azevedo, J., and D. L. Morgan.
1974. Fog precipitation in coastal California forests. Ecology 55:1135-1141.

Cheng, J. D., T. A. Black, J. de Vries, R. P. Willington, and B. C. Goodell.
1975. The evaluation of initial changes in peak streamflow following logging of a watershed on the west coast of Canada. Int. Assoc. Sci. Hydrol. Publ. 117:475-486.

Ekern, Paul C.
1964. Direct interception of cloud water on Lanaihale, Hawaii. Soil Sci. Soc. Am. Proc. 28(3)419-421.

Harr, R. Dennis.
1976. Forest practices and streamflow in western Oregon. USDA For. Serv. Gen. Tech. Rep. PNW-49. 18 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Harr, R. Dennis, Richard L. Fredriksen, and Jack Rothacher.
1979. Changes in streamflow following timber harvest in southwestern Oregon. USDA For. Sev. Res. Pap. PNW-249, 22 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Harr, R. Dennis, and James T. Krygier.
1972. Clearcut logging and low flows in Oregon coastal watersheds. Res. Note 54, 3 p. Oreg. State Univ. Forest Res. Lab., Corvallis.

Harr, R. Dennis, Warren C. Harper, James T. Krygier, and Frederic S. Hsieh.
1975. Changes in storm hydrographs after road building and clear-cutting in the Oregon Coast Range. Water Resour. Res. 11(3):436-444.

Harr, R. Dennis, and F. Michael McCorison.
1979. Initial effects of clearcut logging on size and timing of peak flows in a small watershed in western Oregon. Water Resour. Res. 15(1):90-94.

Harris, D. D.
1973. Hydrological changes after clearcut logging in a small Oregon coastal watershed. J. Res. Geol. Surv. 1(4):487-491.

Harris, D. D.
1977. Hydrologic changes after logging in two small Oregon coastal watersheds. U.S. Dep. Int. Geol. Surv. Water-Supply Pap. 2037. 31 p.

Hewlett, John D., and J. D. Helvey.
1970. Effects of forest clear-felling on the storm hydrograph. Water Resour. Res. 6(3):768-782.

Hibbert, Alden R.
1967. Forest treatment effects on water yield. p. 527-543. In W. E. Sopper and H. W. Lull (eds.), International Symposium on Forest Hydrology. Pergamon Press, New York.

Hornbeck, James W.
1973. Storm flow from hardwood forested and cleared watersheds in New Hampshire. Water Resour. Res. 9(2):346-354.

Isaac, Leo A.
1946. Fog drip and rain interception in coastal forests. USDA For. Serv. For. Res. Note No. 34, p. 15-16. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Luchin, Luciano V.
1973. High yield from the Bull Run watershed. J. Am. Water Works Assoc. March, p. 183-186.

Neter, John, and William Wasserman.
1974. Applied linear statistical models. Richard D. Irwin, Inc., Homewood, Ill. 842 p.

Oberlander, G. T.
1956. Summer fog precipitation on the San Francisco Peninsula. Ecology 37:851-852.

Reinhart, Kenneth F., Arthur R. Escher, and George R. Trimble, Jr.
1963. Effect on streamflow of four forest practices in the mountains of West Virginia. USDA For. Serv. Res. Pap. NE-1, 79 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Rothacher, Jack.
1970. Increases in water yield following clear-cut logging in the Pacific Northwest. Water Resour. Res. 6(2):653-658.

Rothacher, Jack.
1971. Regimes of streamflow and their modification by logging. p. 40-54. In J. Morris (ed.), Symposium on Forest Land Uses and Stream Environment. Continuing Education Publications, Oreg. State Univ., Corvallis.

Rothacher, Jack.
1973. Does harvest in west slope Douglas-fir increase peak flows in small forest streams? USDA For. Serv. Res. Pap. PNW-163, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

U.S. Army Corps of Engineers.
1956. Snow hydrology. U.S. Army Corps Eng. Portland, Oreg. 437 p.

U.S. Army Corps of Engineers.
1960. Runoff from snowmelt. Eng. Man. 1110-2-1406. 75 p.

Vogl, R. L.
1973. Ecology of knobcone pine in the Santa Ana Mountains, California. Ecol. Monogr. 43:125-143.

English Equivalents

1 centimeter (cm)	=	0.39 inches
1 meter (m)	=	3.28 feet
1 kilometer (km)	=	0.62 mile
1 hectare (ha)	=	2.47 acres
1 liter per second per hectare (liter/s·ha)	=	9.15 cubic feet per second per square mile

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

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3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

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Mailing address: Pacific Northwest Forest and Range Experiment Station
809 N.E. 6th Ave.
Portland, Oregon 97232

Harr, R. Dennis.
1980. Streamflow after patch logging in small drainages within the Bull Run Municipal Watershed, Oregon. USDA For. Serv. Res. Pap. PNW-268, 16 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Annual water yields and size of peak flows were not changed, but low flows decreased significantly after patch logging in two small watersheds.

KEYWORDS: Streamflow -)forestry methods, logging (-hydrology, patch logging, Oregon (Bull Run Watershed)

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